4.0 MANAGEMENT, SCHEDULE, AND BUDGET

4.1 Management

The key features of the Constellation-X Project are clear interfaces and a direct, proven management structure. The management approach was designed to provide clear and uncomplicated lines of authority with one Project Manager (PM) in charge, while utilizing the strengths of the SAO/GSFC collaboration and honoring NASA HQ direction for GSFC to perform the management of Constellation-X as a facility-class mission. Constellation-X will build on the experience gained from the successful Chandra model, where SAO teamed with MSFC in a fashion similar to that proposed for Constellation-X. Both GSFC and SAO have extensive flight experience and have worked together on several previous missions (e.g., SWAS, SOHO, Spartan, U.S. ROSAT Data Center). They have successfully collaborated on Constellation-X for the past 6 years.

The management approach for Constellation-X has been successfully used at GSFC for many years. Throughout its history, GSFC has launched more than 250 space missions and has a proven track record of utilizing its resources, from engineering support to upper management, to ensure mission success. The interfaces and relationships among GSFC, SAO, and the other organizations, both in the technology development and in the implementation, are very clean and well understood, as described in the following paragraphs.

The SAO contribution to the Project makes maximum use of its experience with Chandra, both in telescope and instrument development, and in operations. Much of Chandra's design and analysis experience will be used for Constellation-X, and SAO's management experience will be invaluable in supporting the overall management of the Project. In many cases, Constellation-X key individuals will be those who worked on Chandra.

4.1.1 Mission Formulation

In 1996, following selection of their independent proposals in response to NASA's solicitation for new concepts, GSFC (Dr. Nicholas White) and SAO (Dr. Harvey Tananbaum) combined similar ideas into a collaborative program. They requested and received approval from NASA HQ to form the FST for this joint endeavor, and that group continues to provide scientific guidance. Given the anticipated performance improvement compared with previous missions, the technology needed to be extended and proven. Hence, the Project was started as a technology development effort. Since then, several organizations have been developing the technologies to TRL 6, according to the technology development schedules in Foldouts 8 and 9. In addition, the other formulation activities needed to develop a mission concept were initiated and are proceeding. All technology and formulation work is geared toward meeting the mission requirements.

4.1.1.1 Organization

The Constellation-X formulation organization (Figure 4-1) shows the integrated nature of the Project, while retaining clear lines of authority. The Project Management is seated in the NMP/SEU Program within the FPPD at GSFC. The NMP/SEU theme, led by an experienced Program Manager, Dr. Bryant Cramer, provides program-level support and guidance. The Project presents a status monthly to the Director of FPPD and the GSFC Executive Council, which is headed by the Deputy Center Director and includes the heads of each Directorate. The guidance and support from these two groups is of great value in obtaining Center resources and in getting the high-level attention needed to resolve Project issues. Quality Assurance and System Safety support is supplied using the resources of the long-established Quality organization at GSFC. The OSSMA Directorate personnel work on the Project, but retain an independent reporting path to the Center Director. The Project must respond to issues raised through the OSSMA. As an example of added value, the materials group at GSFC has been actively engaged in selection of a workable epoxy for the SXT reflector development. Both GSFC and SAO provide additional scientific leadership and support drawing from more than 35 years of experience in X-ray astronomy. Other directorates at GSFC supply matrixed support, including discipline engineering, systems engineering (including the lead Mission Systems Engineer [MSE]), Instrument Managers, business and procurement management, and ground system and operations support. SAO supplies system engineering, operations and ground system design support, and engineering support.

In the science area, GSFC supplies the Project Scientist, Deputy Project Scientist, and one of the

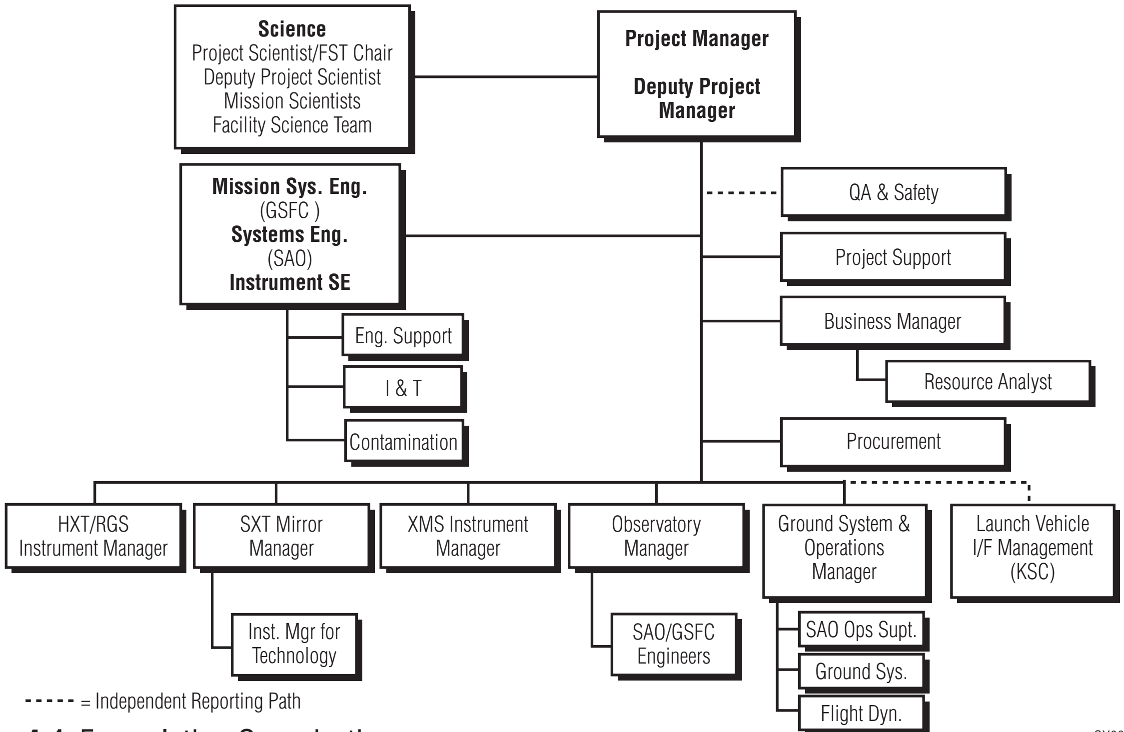


Figure 4-1: Formulation Organization

Mission Scientists. SAO supplies the FST Chair and the other Mission Scientist. The FST is an international group of scientists recognized as experts in the field of X-ray astronomy, brought together to provide science guidance and requirements development during the formulation phase. Technology development activities are led by their respective IPT lead, with a cognizant manager on the Project staff. Due to the complexity of the SXT FMA development and the need for an early start, an SXT FMA Manager is identified now, in addition to the Instrument Manager for technology development. The FMA manager will oversee the SXT mirror production activities, including phasing from technology development to production, procurement of mandrels, and soliciting vendor interest for flight production.

4.1.1.2 Teaming Arrangement and Institutional Commitments

The Constellation-X Project in the formulation phase is a collaboration among several institutions. GSFC and SAO form a core science and management group to oversee the concept development of the mission elements. The GSFC/SAO collaboration has been a strong one, as evidenced in the progress made in the last 6 years including development of the mission concept and the documenting of mission requirements. There has been a synergistic relationship, utilizing the best of both organizations to advance the Project. Both organizations are committed to the technology development phase, as illustrated in the organization chart. A Cooperative Agreement held by GSFC for SAO is the legal mechanism for transfer of funds and establishment of institutional commitment.

Institutions were selected through a 1998 NRA to develop the required technologies for the X-ray Microcalorimeter, the RGS CCDs and Gratings, and the HXT. Upon selection of the technology developers, IPTs were formed, combining the best expertise of the various organizations for specific technologies. From the selected proposals, an IPT lead was assigned to manage each technology effort and report to the Project. While the major activity of each group is to develop the key technology, they also perform the formulation activity of defining the instrument concept. SXT mirror technology work was deemed so critical to mission formulation and implementation that an IPT lead was assigned at GSFC, with support from SAO and MSFC.

All of the organizations performing the technology development activities have had extensive experience in the areas for which they are responsible. Table 4-1 lists the organizations, their technology being developed, and relevant experience.

Each of these organizations is funded according to the funding profile shown in Section 4.3. Grants for the universities and funding commitments for the government organizations are sized to enable a technology development program to reach the TRLs as indicated in the technology development schedules, Foldouts 8 and 9.

Teaming relationships and commitments within each IPT are detailed in Section 4.1.1.5.

Table 4-1: Teaming Arrangements

Organization	Lead Personnel	Responsibility	Relevant Experience
Project Level			
GSFC	Nick White, Kim Weaver, Robert Petre, Scott Lambros, Jean Grady	Project management; science management; mission design and engineering	RXTE, CGRO, MAP, IMAGE, Astro-E, HST, GLAST, Terra
SAO	Harvey Tananbaum, Jay Bookbinder, Robert Rasche	Project management support; science management; mission design and engineering	Chandra, ROSAT, Einstein, UHURU, TRACE, Solar-B, NICMOS
Technology Developments			
SXT Mirror			
GSFC	Robert Petre*	Management; reflector development; structure and alignment; optical design	BBXRT, ASCA, Astro-E
SAO	Bill Podgorski	Systems engineering; analysis	Chandra, Einstein
MSFC	Steve O’Dell	X-ray testing; mandrel procurement	Chandra, Einstein
MIT	Mark Schattenburg	Si alignment structures	Chandra
RGS			
Columbia U.	Steve Kahn* Andrew Rasmussen	Management; optical design; structure design; alignment	XMM-Newton, RGS
MIT	Mark Schattenburg	Grating and substrate production; alignment; module design	Chandra, HETG
Colorado U.	Webster Cash	Off-plane diffraction grating (alternate design)	FUSE
MIT	George Ricker	CCD readout array	Chandra ACIS; Astro-E CCD; ASCA SIS; HETE
XMS			
GSFC	Richard Kelley* Caroline Stahle	Management; calorimeter development; TES; ADR; Cooler Oversight	Astro-E/E2, XQC suborbital
NIST	Kent Irwin	TES; SQUID readout	SCUBA-2
SAO	Eric Silver	NTD technology (alternate design)	SRRT, B-MINE
JPL	Ron Ross	Cryocooler ACTDP management	many years cryocooler research
HXT			
Caltech	Fiona Harrison*	Management; CdZnTe detectors; ASIC readout	HEFT, ACE, STEREO
Columbia U.	Charles Hailey	Glass optics	HEFT, XMM
DSRI	Finn Christensen	Multilayers on glass	SODART, HEFT
GSFC	Jack Tueller, Will Zhang	CdZnTe material, contacts; Glass mirror substrates	Astro-E, InFOCμS, Swift
LLNL	William Craig	Glass optics mechanical design	HEFT, XMM
MSFC	Brian Ramsey	Nickel optics	HERO, Chandra
SAO	Paul Gorenstein	Multilayers on nickel	Chandra, Einstein, Apollo
U. Brera	Oberto Citterio	Nickel optics	SAX, XMM, JET-X
*IPT Leads			

4.1.1.3 Decision-Making Process

The final authority for all decisions is the GSFC Project Office, headed by the PM. The PM is ultimately responsible for all decisions made on the Project. While all inputs from the collaboration are considered and an attempt is made to reach decisions by consensus, particularly with the Senior Management Team (defined below), the PM is ultimately responsible and accountable for the successful completion of the Project. The PM, in turn, reports to GSFC upper management and to NASA HQ and must abide by decisions made at those levels. This process has been successful for developing the technology programs and mission architecture for the last 6 years.

A Senior Management Team has been established to support major decisions that affect project direction. This group includes the PM, Deputy Project Manager, Project Scientist, Deputy Project Scientist, FST Chair, and Mission Scientists (from GSFC and SAO). This group communicates continuously by regularly scheduled status meetings and by phone, email, and ad-hoc meetings.

The Project Scientist and the FST Chair are responsible for defining the science requirements and performance. They must consider inputs from the FST, other inputs from the science community and scientific review panels, and mission feasibility. Once agreed upon, requirements are configuration controlled by the Project. Any changes require concurrence by the Project Scientist, FST Chair, and the PM. Any science decisions which affect mission feasibility require input from the Project, with final authority from the PM.

The MSE is accountable to the Project Management for technical decisions made on the mission architecture. The MSE oversees this development and generates technical allocations for each element. If requests are made to change technical allocations, the MSE is responsible for making recommendations, but the final decision for all allocation changes lies with the PM. The lead MSE resides at GSFC.

Each IPT lead has the responsibility to develop their technology to TRL 6 within the allocated budget and schedule, and is responsible for the day-to-day decisions on their program. They are accountable to the Project Office and report status on a regular basis. Much of this reporting is made in a larger group, consisting of GSFC and SAO key personnel and often the other IPT leads. For example, status is given at FST meetings that occur twice yearly; open team meetings/telecons occur on a bi-weekly basis. Yearly executive meetings with the IPT leads review and discuss the funding for each technology for the following year. All budget requests are discussed by the group, with the overall Project schedule and performance as the context for recommendations. In this way, IPT leads have input into project decisions that may impact their technology program, or instrument concept development.

One of many examples that illustrates the success of the decision-making process is the decision to baseline segmented technology, instead of shells, for the SXT mirror. This decision involved the SXT IPT, and discussions with the GSFC and SAO management team. The technology development results along with cost and schedule projections were considered as a group and a decision was made by the PM, which was acceptable to everyone.

Another example involves the decision to baseline Event Driven CCDs for the RGS development. In addition to the process previously described, an independent panel of CCD experts was convened in a peer review to formalize the review and decision process.

4.1.1.4 Responsibilities and Experience of Team Members

Table 4-1 lists the organizations involved in technology development and formulation activities, their responsibilities, and relevant experience. All lead organizations have outstanding records for cost and schedule performance for flight deliveries as indicated in the table.

GSFC has built space flight instrumentation since its establishment in 1959 and is respected internationally for its accomplishments in Space and Earth Sciences. GSFC recent mission development experience includes RXTE, CGRO, COBE, MAP, HST, EOS-Terra and Aqua. GSFC has launched more than 250 missions, continually refining a proven management system and mission and instrument development capability, and generating corporate knowledge that is available to Constellation-X.

SAO has also participated in many successful missions. Chandra is the most similar to Constellation-X, and several people who have worked on Chandra are participating in Constellation-X. SAO team members have built the first orbiting X-ray astronomy satellite, UHURU; the first orbiting X-ray telescope to observe objects other than the Sun, Einstein; and the High Resolution Imager that flew on ROSAT. SAO shared responsibility for the U.S. ROSAT Data Center with GSFC and had responsibility for the Einstein General Observers and Data Center. SAO now managers the Chandra Operations and Science Center.

Project Management resides at GSFC. Systems Engineering is a combined effort between GSFC and SAO. The MSE located at GSFC concentrates on the overall mission elements and has also been acting as the Observatory Manager during much of the early development phase. This includes managing the observatory concept development, utilizing the engineering staff for concept development and conducting trade studies. The engineering staff is matrixed from the Applied Engineering and Technology Directorate (AETD) at GSFC and includes all the major disciplines needed to design a spaceflight mission, as learned from the many missions built at GSFC. The SAO Systems Engineering effort has concentrated largely on supporting the TM concept development, in particular SXT development and the TM architecture. The structural engineering of the TM is being performed at GSFC. The thermal engineering has been shared between GSFC and SAO, which illustrates the integrated effort between the two organizations. Requirements flowdown has been a major systems engineering activity during the formulation phase. The operations concept development has been centered at SAO, as was the case with Chandra, with the intention that SAO will perform mission operations after launch, as well as the science operations in conjunction with GSFC.

4.1.1.5 Technology Development Management

This section describes the relevant experience of the organizations involved in each of the technology development areas.

SXT Mirror: The SXT mirror technology development team has members from several institutions, each with well-defined responsibilities (see Table 4-1). The team is highly integrated and takes advantage of the strengths of the contributing organizations. Industry consultants have included Bauer Associates, RJH Scientific, and Zeiss. All participating organizations are fully committed to supporting the SXT development. Currently all development is funded by the Constellation-X Project. In prior years the GSFC, MIT, and MSFC X-ray groups made substantial institutional contribution to the SXT development via SR&T, CETDP, IR&D and facilities funds.

The GSFC X-ray group is the world leader in the development and production of segmented X-ray mirrors for flight experiments. The segmented mirror was invented at GSFC approximately 25 years ago. Since then, the group has supplied mirrors for BBXRT, ASCA, Astro-E, and suborbital programs. It is currently building five segmented mirrors for Astro-E2. SAO provides the systems engineering and analysis expertise it supplied for the Chandra mirrors as well as its extensive involvement in the fabrication, assembly, and calibration of the Chandra and Einstein X-ray optics. MSFC has unique X-ray test facilities, and together with SAO, organized and implemented the Chandra calibration. The MIT group has pioneered the development of Si microcombs for use in the SXT and Constellation-X gratings.

RGS: The IPT Lead is at Columbia University and is responsible for optimizing the design of the spectrometer. The MIT group is responsible for grating technology development for production improvements such as substrate flattening and assembly concepts. Another group at MIT is responsible for development of the BI EDCCDs, their characterization and design. The University of Colorado is responsible for examining alternate optical design concepts, including novel, high ruling density, off-plane gratings. All participants in the technology development are fully committed to supporting the RGS development. Development is supported by Constellation-X technology development and leveraging activities with SR&T and DARPA, for example.

The IPT lead has experience relevant to all project phases with the RGS aboard XMM-Newton. MIT planned and built the HETG grating spectrometer aboard Chandra and has the capability to devise new precision structures and fabricate them. MIT also has more than 35 years of experience in other X-ray missions, including 0S0-2, -7, SAS-3, HEAOs 1 and 3, Einstein, RXTE, and HETE. The Colorado group has experience designing and building astronomical instrumentation as a co-investigator for Lyman-FUSE. The MIT CCD group has extensive experience in designing and building CCD array cameras and their associated electronics, including CCD instruments for Chandra, ASCA SIS and Astro-E.

X-ray Microcalorimeter Spectrometer (XMS): XMS technology team members have extensive experience in all facets of microcalorimeter array development and readout as well as low temperature systems for space flight use. The GSFC Laboratory for High Energy Astrophysics is a world leader in inventing and developing state-of-the-art detector systems for high energy astrophysics, with experience dating back to the 1960s on suborbital payloads and orbiting observatories since then that include OSO-8, Ariel-V, HEAO-1, HEAO-2, BBXRT, ASCA, Astro-E, and Astro-E2. GSFC developed the X-ray microcalorimeter with both implanted Si arrays starting in the early 1980s, and TES arrays starting in the mid 1990s. The GSFC Cryogenics Branch has developed a number of space flight cryogenic instruments and ADRs. They are also experts in space cryocooler systems and have worked with a number of companies to develop this technology for a variety of NASA programs. Lockheed-Martin, TRW, and Ball Aerospace are cryocooler developers working on this project. The Cryogenic Branch's work on Astro-E/E2 is particularly relevant, and the GSFC team is well qualified to develop and carry out a technology plan with a high degree of cost certainty.

The NIST group pioneered and developed the TES thermometer for microcalorimeters and are world leaders in TES fabrication and SQUID readout. In addition to the work they are doing on X-ray TES arrays, they are responsible for an ambitious multiplexed TES 6400-pixel submillimeter array for the James Clerk Maxwell Telescope. They have also developed laboratory TES systems for materials analysis.

SAO is developing an alternate calorimeter concept using NTD technology. Utilizing their experience of building microcalorimeter arrays, they have been proving this technology through laboratory astrophysics experiments. SAO is partnering with the Lawrence Berkeley National Laboratory, which has long experience of building flight instruments. The decision of which technology to move forward will be made in 2004.

HXT: The HXT technology development program is being carried out by an international team of experts in X-ray optics, multilayer coatings, and detector development consisting of the leading groups in hard X-ray astrophysical instrumentation who are currently involved in major efforts to develop focusing capability for the hard X-ray band.

The HXT team includes members from institutions that have developed major facilities for Chandra, XMM, ASCA, Astro-E, Swift, STEREO, and ACE. Therefore, the collaboration has access to major production, calibration, and processing facilities both at NASA Centers and universities that have been committed to carrying out the Constellation-X HXT development program.

4.1.1.6 Mission Architecture Development

During the early formulation phase, mission architecture studies have already helped to define the spacecraft concept, the TM concept, the ground systems and operations concept, the launch vehicle capabilities, orbit, initial I&T flow, and assignment of technical resource allocations to each element. systems engineering studies, such as determining alignment concepts and examining realism of pointing error allocations and performance have also been conducted. In 1998, through a Cooperative Agreement Notice to perform an architecture study, TRW and Ball Aerospace designed independent solutions to the Constellation-X requirements. This information was reviewed and used as input, along with a third input from GSFC and SAO engineering to design a "Reference Mission Description[24]" document. The reference configuration used the instrument concepts that were developed by the technology development IPTs, along with the GSFC and SAO engineers. This reference configuration was used to demonstrate the validity of the Constellation-X concept, to provide a starting point for designing the instrument concepts, and for costing. The reference configuration shows that the required performance can be met.

These studies will continue through the formulation phase. As results of further studies and trades become available, the reference configuration will be updated accordingly. In particular, the following are planned:

Mission Phase A and B : The Phase A studies will be multiple contracts to industry. Multiple contracts will ensure independent technical designs, so the best available technical solutions are incorporated into the mission architecture. The Phase A studies will be for the observatory architecture: the combined spacecraft and TM. Following completion of Phase A, an open competition will result in selection of one vendor to perform a Phase B study (this prime contractor will follow-on with Phase C/D). The Phase B activities will continue to develop the preliminary design.

Science and Operations Center: Led by SAO, the Operations Concept Document[25] will be baselined, leading to the definition of the ground system architecture and the process for integrating CXSOC planning and development activities with the existing Chandra Operation Center. Activities include specification of the mission data system and archive architectures, refinement of the calibration plan, and development of the data management plan.

4.1.1.7 Risk Management

The principal risks during the formulation phase are the risks associated with the development of the optics and instruments. All technologies have heritage from previous designs which reduce their risk level. However, given that the technologies are an extension of what has been done before, and development is required, there is necessarily an element of risk. The technology development program is the first line mitigation for this risk. That is, the program is in place to develop the required technologies to the required performance for Constellation-X, before moving into the instrument development phase. Technology investigations also address process development. For example, the SXT mirror fabrication and assembly process is being studied and tested extensively to ensure that it can be done within the required schedule and cost.

The Project carries margin in performance, cost, schedule, and technical resources such as mass and power, in order to make trades to optimize the mission and to manage problems such as insufficient progress in technology development, unexpected system interactions, or changes in cost/schedule requirements. Technology development progress is monitored on a regular basis, and backup options are discussed and investigated as part of the technology developments.

Specific risk areas for each technology are discussed in the technology development sections, including mitigations, alternate designs and decision points for invoking back-up options. These are summarized in Table 3-2.

4.1.1.8 Transition from Technology Program to Flight Project

The Constellation-X Project plans ensure a smooth and seamless transition into the implementation phase. Moving toward implementation, the staff level will increase until it is at the full organization shown in the implementation organization chart (Figure 4-2). Project controls will be added at the appropriate phase (e.g., documents and requirements will be put under formal configuration control in Phase A). Changes will only be allowed if approved by a formal control board, chaired by the PM. Schedule control will continue throughout formulation and implementation, becoming more formalized after the flight contracts are awarded. Technical reserves requirements will be established in formulation and monitored and controlled during implementation. The approval process for moving into the implementation phase will use the NASA approach of an independent NAR. This is a rigorous approach to certify the readiness of the Project for the next phase.

The general approach for the Constellation-X Project to enable a smooth transition from formulation to implementation is as follows: The technology and mission concepts are developed in the formulation phase. Most of the elements are then competed with issuance of a NASA solicitation (see Table 4-2 for the Constellation-X acquisition strategy for each element). The Project then oversees the development by the element-providers during the implementation phase. The Project oversees the entire process and provides the management, systems engineering, and science direction and requirements.

4.1.1.8.1 Acquisition Strategy

Following is a strategy that will allow a smooth transition into the implementation phase. It is used for baseline planning, and must be approved by NASA HQ before being implemented.

Instruments: Each of the flight instruments (XMS, RGS, HXT) will be solicited with a

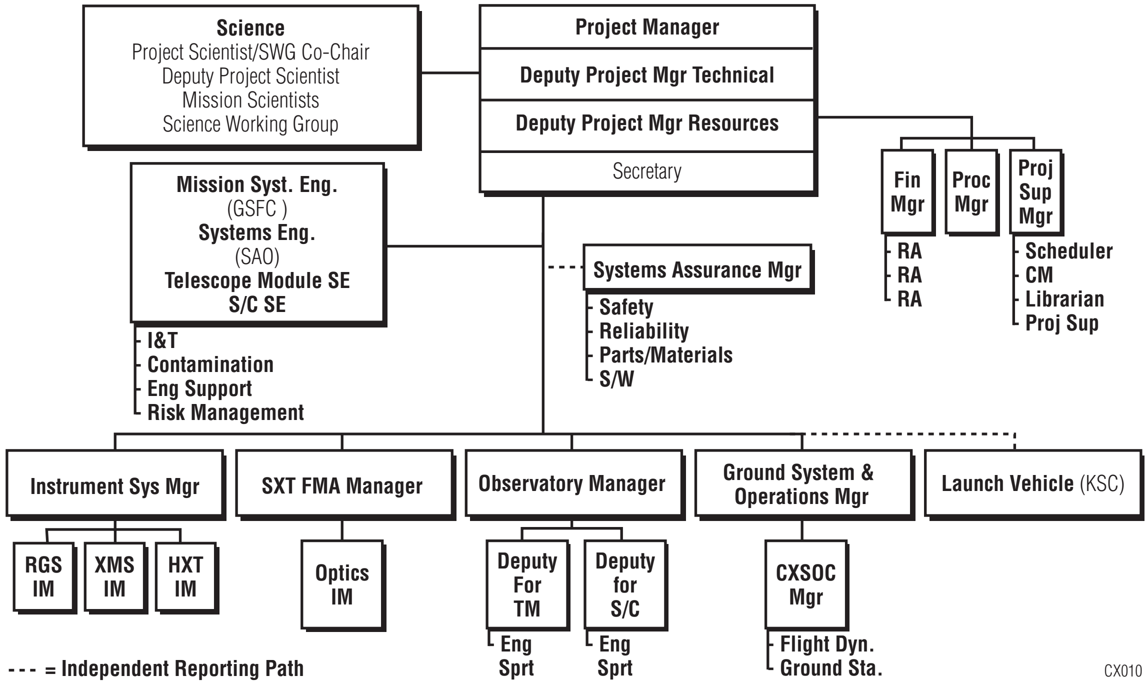


Figure 4-2: Implementation Organization

NASA HQ issued AO. A Principal Investigator with supporting institution and proposed teaming arrangements will be selected to deliver the flight-qualified instrument. It is anticipated that proposing organizations will make use of the technology development. However, the AO will be open to alternative concepts if they are mature enough to meet the Constellation-X requirements within the allotted schedule and cost. While it is recognized that the technology development teams have an advantage for the flight selection, there will still be sufficient competition, given that there are multiple teams within the Project who are capable of applying the technologies developed, as well as industry partners who are following the technology developments, by attending open science meetings, and conducting discussions with the technology teams.

Table 4-2: Acquisition Strategy

System	Procurement Strategy	When Contract Required
Instruments	AO	Phase B start
SXT optics	GSFC managed; RFP for vendor; RFP for major procurements	Phase A
Observatory	RFP	Phase B start
Mission Operations Center	Provided by SAO	PDR
Science Operations Center	Provided by SAO ; shared with GSFC	PDR
Ground stations	Leased commercial	Observatory I&T
Launch vehicle	KSC procurement	L -30 months
General Observers	SAO call for proposals	L +4 months

SXT Flight Mirror Assembly: The mirror assembly development will be managed at GSFC, with engineering and science support from GSFC and SAO. A contractor will be selected via an RFP to produce the FMA. This includes producing the mirror segments, all the systems engineering and integration, with the PI developed gratings provided for integration as government-furnished equipment (GFE). Prior to vendor selection, a study contract will allow two potential vendors to further refine the fabrication and assembly process (Phase A activity). This will be accomplished by an RFP. The flight forming mandrels and replication mandrels will be provided to the vendor as GFE. This will also be a GSFC competitive procurement. The vendor will be selected early enough to work hand-in-hand with the technology development organizations, to facilitate technology transfer, and to make use of the lessons learned. The schedule for the SXT acquisition activities is shown in Appendix B, page B-4.

Observatory: The vendor for the combined spacecraft and TM will be a prime contractor who will have responsibility for both elements, the interfaces between them, the instruments and mirrors, and the I&T, after receiving fully qualified instruments and SXT FMA. Using a prime contractor will ensure ownership and responsibility for the integrated systems design and interface management for the entire observatory. There has been, and will continue to be, active vendor involvement; there has already been a response to a CAN for mission design, an RFI for spacecraft design and cost, and unsolicited design work from several potential vendors.

An RFP will be released to industry for a 9-month Phase A study per the schedules shown in Appendix B, pages B-24 and B-25 (described in Section 4.1.1.6). It is likely that two vendors will be selected. Toward the end of the formulation contract, a separate RFP will be generated to solicit vendors for a final design and implementation contract (essentially a Phase B/C/D contract). The timeline for selection of this contract is shown in Appendix B, Page B-24 and B-25. This method has been utilized successfully on contracts such as the Advanced Technology Microwave Sounder. This RFP will be an open solicitation, not limited to the vendors who performed the formulation studies. The contract will be structured such that continuing into the implementation phase is contingent on NASA HQ approval.

Ground System: The CXSOC will be located at SAO, co-located with the Chandra X-ray Center, making maximum use of NASA's investment in the Chandra experience, personnel, and infrastructure. The Science Operations Center will be a partnership between the SAO Chandra X-ray Center and GSFC (HEASARC and its co-located science centers), with SAO as the lead. The exact roles and responsibilities between SAO and GSFC will be determined after selection of the instruments. The ground stations will be leased commercial sites.

Launch Vehicle: This procurement will be managed by the Kennedy Space Center, as per NASA practice.

General Observers: A robust GO program will be managed from the Science Operations Center. Calls for Proposals will be issued, and selected proposers will be awarded grant funding to perform their science investigations using Constellation-X data.

4.1.1.8.2 Transition Activities

Specific activities will enable a smooth transition from formulation to a flight project.

Concept Development: Beginning in formulation, concepts for the instruments and observatory are developed and used for design, proof-of-concept, and costing. These concepts will be refining the reference configuration and are developed by the GSFC and SAO engineering teams, with input from industry, and the IPTs for the instrument concepts. A manager on the Project (e.g., IM, OM, SE) is assigned to each element to manage the concept as it matures into flight designs.

Requirements Development and Configuration Control: Requirements development began early in the Project (evidenced by the Top-Level Requirements Document[4]) and will continue during the transition phase. Traceability will ensure consistent monitoring of requirements from the beginning of the Project to final design and verification. Configuration control will be in effect *before* flight contracts are awarded.

Reference Mission Description Document: This is used to keep track of one particular architecture that can satisfy the Constellation-X requirements. Responses to solicitations will be compared against this reference, to verify their validity.

Systems Engineering: Requirements flowdown and traceability ownership, technical resource ownership, system studies, such as TM concept and associated pointing performance, all systems engineering activities, will be carried through the transition phase.

Mission Studies: Phase A studies will refine the overall mission architecture and solicit inputs from industry. This will inject a broader array of technical ideas and solutions that will be used in the final design.

Science: Science support is based on internationally recognized leadership and early definition of science requirements configuration controlled through the transition process.

Management: The organization is consistent with GSFC organizations used on many successful projects. The GSFC/SAO collaboration has proven to work well and follows experience from other similar space projects.

Risk Management: This activity will carry on throughout the formulation and implementation phases, ensuring feasibility and making informed decisions at pre-defined trigger points.

Cost Control: Many of the activities during this time period will be in an effort to find the most cost effective designs and processes. Cost will be a factor in the trade studies and architecture studies performed during this time.

4.1.2 Mission Implementation

4.1.2.1 Organization

The Constellation-X Implementation organization shown in Figure 4-2 is consistent with GSFC Project organizations that have successfully managed many missions. The formulation organization staff has increased to provide the level needed to manage the implementation, consistent with the size of the Constellation-X Project. Specific changes from the formulation phase are as follows:

The PM for the implementation phase will be chosen approximately one year before moving into the implementation phase. The Director of the FPPD will select the person most appropriate for this position, who may or may not be the same as the formulation PM. The year lead time allows the PM to come up to speed, have an impact on project direction, and ensure a smooth transition before coming into the full swing of implementation.

A complete Systems Assurance Program will be in place. As in the formulation phase, this support will come from the Office of Systems Safety and Mission Assurance Directorate, and will include system assurance, safety, reliability, software assurance, software IV&V from the West Virginia facility, as well as parts and materials engineering from the AETD.

The systems engineering staff will be augmented, and formal risk management will be added to the systems engineering duties.

An added Instrument Systems Manager is responsible for the successful delivery of all instruments, and manages the team of Instrument Managers, one for each instrument, to accomplish this task.

The Observatory Manager becomes the Technical Officer on the Prime Contractor contract. Given the magnitude of the job, two deputies, one for the TM and one for the spacecraft, will be added to oversee their respective developments. A TM and spacecraft SE will be added for support.

A manager for the Constellation-X Science Operations Center will be selected by the time of implementation.

The business function of the Project will be expanded to be commensurate with the size of the Project.

As has been done on other projects (e.g., GLAST, Chandra), the FST will be disbanded by this point, having served its purpose of initially defining the Constellation-X science requirements. It will be replaced with a Science Working Group (SWG). The SWG will be selected through the instrument AOs and will consist, as a minimum, of one or two representatives from each team. It is anticipated that the co-chairs of the SWG will be the Project Scientist and the former Chair of the FST. The SWG exact makeup will be determined by NASA HQ at the time of AO release.

During implementation, all contracts to hardware developers will be in place. Each element will have a SE, which will be part of a Systems Engineering IPT, led by the MSE. In addition, since the Observatory will be the responsibility of a Prime Contractor, they will have significant systems engineering responsibilities for the complete observatory, including interfaces to the instruments, mirrors, and ground system. This is an advantage of using the Prime Contractor model, with a systems engineering cadre on the Project.

4.1.2.2 Teaming Arrangement and Institutional Commitments

As in the formulation phase, the Project is a collaborative effort between GSFC and SAO, with the Project Management performed at GSFC. The institutional commitments of the two organizations will continue throughout the implementation Phase. It is planned that the science management team, specifically the Project Scientist, the SWG Co-Chair (the FST Chair in formulation), and the Mission Scientists (one from GSFC and one from SAO) will remain the same.

The organizations which will develop the flight hardware will be solicited during formulation, and so they are not currently known. However, as a risk mitigation activity industry sources have been extensively pursued to verify that there is interest and capability to provide what is needed.

4.1.2.3 Decision-Making Process

The decision-making process during the implementation phase will carry over from the formulation phase. The PM is still accountable for the entire mission success and has the authority and responsibility for all Project decisions. The Senior Management Team consisting of GSFC and SAO personnel will continue to be used and to make the best use of the experience of the personnel from the two organizations. The leads (Project Scientist and SWG Co-Chair) will be the same people as during the formulation phase: Dr. Nicholas White, GSFC, and Dr. Harvey Tananbaum, SAO, and will represent the science inputs to the Project.

During implementation, the Level 1 Requirements will be finalized and will be a guiding document from NASA HQ to the Project. Decisions will be measured against meeting those requirements. If those requirements cannot be met, or if they require a funding level greater than the allowable guideline, HQ will be made aware of the situation and will make the final decision on how to proceed. Options include an increased funding level, implementation of descopes (including stretching the schedule), or, in a severe case, cancellation of the Project.

4.1.2.4 Responsibilities and Experience of Team Members

Senior team members for the Project Management, Science Management, and SXT management for the formulation phase are transitioned to the implementation phase with similar roles and responsibilities (see Section 4.1.1.4).

4.1.2.5 Instrument Development Management

The organizations that will develop the flight instruments will be solicited during Phase A, as described in Section 4.1.1.8.1 Acquisition Strategy, and so they are not currently known. However, as a risk mitigation activity potential sources have been extensively pursued to verify that there is interest and capability to provide what is needed. At the very least, it is expected that the institutions currently working the technology development activities will propose for the flight instrument development. Each instrument development will have an Instrument Manager to oversee the development, ensure interfaces with other systems, and monitor progress and risk management.

The management team for the SXT optics will look similar to the organization during the technology development phase. The team will continue to be led by the GSFC X-ray Astrophysics Branch, and involve in a highly integrated way participants from the GSFC Optics Branch and Mechanical Systems Center, SAO, MIT, and MSFC. All participants in the technology development program are committed to the flight development. For those major activities that are contracted out, the relevant technology development team lead will remain the point of contact within the team, taking responsibility for technology transfer and overseeing the outside effort. For those areas remaining within the team, the team lead will continue with lead responsibility.

4.1.2.6 Mission Elements Management

A Project Plan will be developed during Phase B to delineate the details of how the Project will manage each element of the Project.

The observatory contract will be managed from GSFC. The AETD will provide discipline engineers (systems, mechanical, thermal, C&DH, communications, electrical, power, propulsion, guidance, navigation and control, software, integration and test, and flight dynamics) to oversee the observatory development. This is a very deep base of support, and additional engineering support can be brought in if needed. This is the normal way GSFC operates and has proven to be a very successful approach. SAO will also provide systems engineering, and some discipline engineering support, for example thermal and structural analysis for the TM, where they have extensive experience from Chandra.

The Office of Systems Safety and Mission Assurance Directorate at GSFC will provide the QA support, and will have an independent reporting chain outside the Project Office. This ensures an independent quality review function.

The ground system and operations function during implementation will be led by SAO.

Ground system expertise from GSFC will also be utilized, and the flight dynamics function will come from GSFC, making use of unique experience with launches to the L2 libration point. The Chandra operations system at SAO will be configured to support Constellation-X in time to support I&T. Chandra is expected to still be operating when Constellation-X is launched, and so facilities, infrastructure, and experienced personnel will be shared without impact to Chandra. The launch vehicle interface will be provided by KSC.

4.1.2.7 Risk Management

During the implementation phase, risk management will be an ongoing activity. A risk management plan will be generated during Phase A, and will detail the activities to aggressively pursue the identification, characterization, mitigation planning (including resource liens, use of project margins, alternate designs and processes), and tracking of progress and decision points, for each identified risk. Each risk will be assigned a risk manager on the Project to regularly monitor its status. Any person on the Project can identify a risk at any time. The status of all risks and potential new ones will be reviewed on a regular basis and reported to the PM for necessary action.

The most significant mission risks for the implementation phase identified at this point and their mitigations to reduce or eliminate the risk are included in Table 4-3 in priority, along with an assessment for criticality (how serious the problem is) and likelihood (the probability of occurrence if no mitigation activities are implemented). Criticality and likelihood levels are defined in Section 3.1. The technology development risks summarized in Table 3-2, and the implementation risks listed in Table 4-3 give the complete picture for all mission phases.

4.1.2.8 Management of Reserves

Technical resources, such as mass, power and volume, are managed by the MSE. Allocations are established, and are continually monitored by the Project. Sufficient mass and power contingency plus project margin will be held so that 30% remains at the time of the AO/RFP release, and with configuration control established at that time. While the MSE is responsible, these resources are also monitored by the

Table 4-3: Top Mission Risks

Risk	Mission Impact	Criticality	Likelihood if no Mitigation	Mitigation
Production and alignment of large number of mirror segments may cause schedule slip	Potential launch delay	High	Medium	• Early studies identifying process and production issues; currently ongoing • Early involvement of potential contractors; discussions in process now; 5 vendors interested • Alignment techniques studied in technology development • Parallel processing as much as possible; in implementation plan • Vigilant management with involvement of scientific and technical staff • Use of schedule/cost contingency
Default of single source for key components	Schedule delay	Medium	Low	• Continue to identify potential back-ups; talking with other vendors • Get commitment from top management; site visits have begun • Use of FFP contract where feasible • Potential funding of back-up vendors during Phase A
Atlas V launch vehicle configuration is not ready (this refers to fairing size, number of solids, etc.)	Schedule delay	Medium	Low	• Use architecture and design that is tailorable for both Atlas V and Delta IV; trigger point is end of Phase B
Loss of XRCF for X-ray testing	Cost	Low	Medium	• Use alternate facilities, e.g., MSFC stray light facility, PANTER (European); trigger point end of Phase B

PM to determine if action is necessary to keep within the required limits. The current amounts of mass and power reserve are shown in Section 2.4.1.3. Performance margins are also monitored and are used to trade off for other parameters (e.g., mass), as long as the minimum science requirements are maintained.

GSFC experience has shown that, for a Constellation-X class mission, schedule contingency of 1 month of funded reserve per year during Phase C/D, is appropriate. Constellation-X holds more reserve than this, as shown on Foldout 5.

After selection of the instrument, mirror and observatory contractors, a percentage of the project reserves–technical, cost and schedule–will be allocated to the developers, to manage with their own team as contingency, with knowledge of the cognizant manager on the Project as contingency. Nominally, this will be 25% of the total reserves and will be the uncertainty applied to the current best estimate. The exact amount will be tailored according to the specific risks for each development, during formulation. For example, the SXT mirror may require more schedule contingency, while the mass may be easier to determine and require less contingency. These values will be documented in an interface agreement with the Project.

The remaining reserve (nominally 75%) is managed at the project level as unallocated margin. Any requests to use more than the nominal 25% for any element must be endorsed by the SE for technical elements, and by the manager (e.g., Instrument Manager) for cost or schedule, submitted to the CCB, and approved by the PM. In addition, the resource usage will be monitored by phase. Allowable values of reserve usage will be determined by major milestone, and documented in the interface agreement with the Project. Monitoring of actual contingency usage compared to these values will be used to establish the health of the development progress. Monitoring will be done by the Project on a regular basis, including monitoring of a developer performance measurement system, and monthly reporting of contingency usage. PM approval is required to increase an allocation for a given phase.

Figure 4-3 shows an example of a time-phased allocation strategy. Past experience has shown that approximately 25% of the technical reserves will be allocated by PDR. Schedule and cost contingency allocations should be minimal at PDR. An additional 25% of the technical reserve and approximately 15-25% of the cost reserves and very little schedule reserve should be allocated by CDR. The remaining technical assets, and cost and schedule for each delivery will be used from CDR through delivery, with a small amount retained for possible workarounds after delivery, during integration and test.

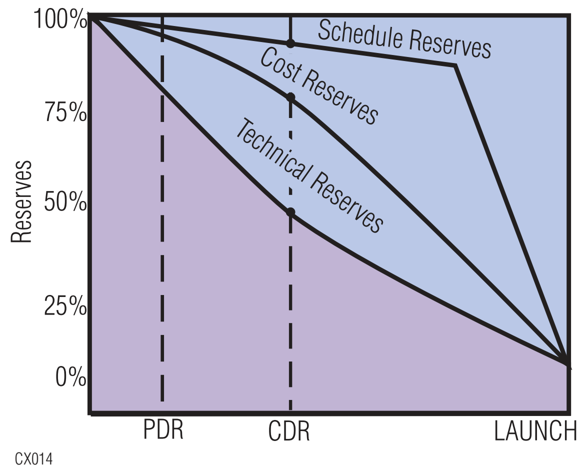


Figure 4-3: Typical Resource Allocation

If resource allocations are exceeded, the following options exist: the first defense is reprogramming, replanning, optimizing work, and checking for areas that can be reduced. When necessary, independent technical teams will be brought in to assist in assessing the situation. The next stage is for the Project to allocate additional reserves. If this is not possible or appropriate (i.e., not enough project reserves, or trend shows no confidence that the situation will improve), descope options developed during formulation will be considered. Any descope option that does not affect Level 1 science requirements can be invoked with PM approval. If Level 1 science requirements are affected, NASA HQ approval is required. The effective monitoring, management, and use of reserves will give high confidence that the Project's goals are met within the allocated reserves. In addition, the experienced technical management, along with an early defined risk and descope plan will minimize the need for use of reserves.

4.2 Schedule

Foldouts 5 through 9 show schedules for Mission Summary, Mission Formulation, Mission Implementation, and Technology Development (two), respectively. Appendix B contains detailed schedules, indicated by WBS element. All schedules were generated in accordance with the WBS, and are tied to funding levels. The detailed schedules in the appendix were used to create the two Technology Development schedule foldouts, which are summarized in the Formulation Foldout. The Formulation and Implementation Foldouts, which capture all mission activities, are summarized in the Constellation-X Summary Schedule Foldout.

All schedules were generated by personnel experienced in their respective activities. The technology development schedules were generated by the IPTs, and have been refined over the past several years. The IPTs also generated the instrument and SXT FMA implementation schedules, using their depth of experience with other similar projects. The observatory schedule was generated by the Project, again using a wealth of experience in other similar projects, and corroborated by information received in the spacecraft RFI. The MO&DA schedule was generated also using the experience of other projects, particularly Chandra, which is the model for Constellation-X MO&DA.

Of particular note is the fact that much effort went into planning for the four observatories. For all flight elements, as much parallel processing will be done as possible, to allow the best schedule advantage. The SXT FMA development makes maximum use of parallel processing to develop the large number of mandrels and reflectors required. This development is on the critical path as shown on the Mission Implementation Schedule (Foldout 7). The technology critical path shown on Foldout 8 includes the mirror development that precedes initiation of mandrel production. Because the SXT FMA is on the critical path, special attention has been given to details of the development and production of the mirrors, as can be seen in the nine pages of SXT FMA detailed schedules in Appendix B. The observatory I&T is generated based on staggering the separate builds. This allows for lessons learned from the first observatory to alleviate problems in observatories 2-4, as well as easing the planning for facility use during environmental test. It is assumed there will be separate teams for each observatory, with overlap where possible to take advantage of the experience gained which can be applied to later builds. The staggering of the first and second observatory builds also creates an additional 3 months of contingency for the first observatory, as shown on the first observatory I&T schedule (Appendix B, page B-26). These two observatories will be placed in orbit on the first launch, December 2010. The same is true for the third and fourth observatories, which will be placed in obit on the second launch 1 year later.

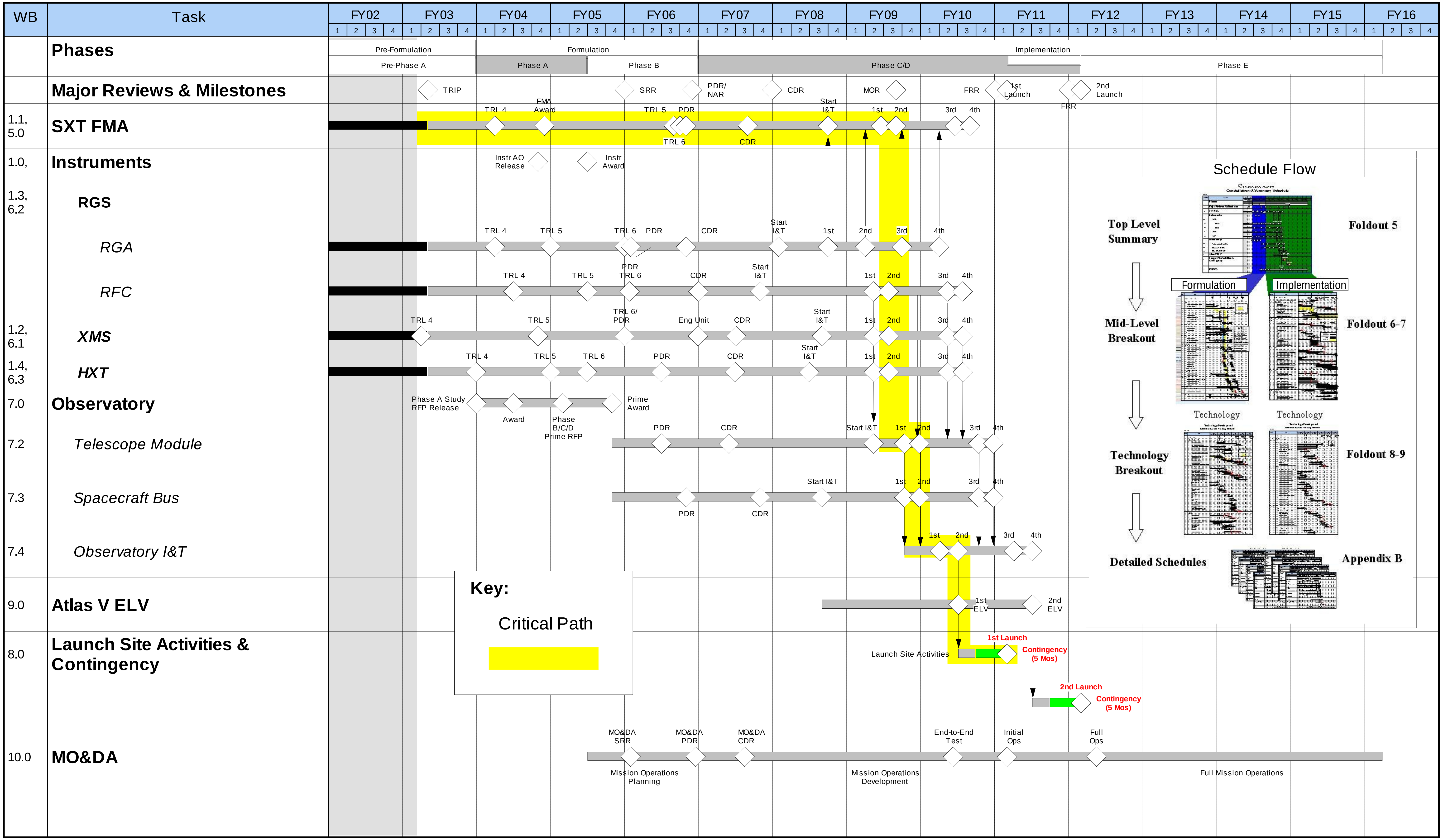
Each technology development as well as all flight elements have slack built into their schedules, as shown in Appendix B and summarized in the table on Foldout 7. This slack is funded and is controlled by the provider of each element. In addition, the Project holds 5 months of funded contingency placed at the end of the development phase, as shown in the Summary Foldout 5. This contingency is controlled by the PM, as described in Section 4.1.2.8.

The Project retains a scheduler to generate and review current schedules. The technology development schedules are reviewed at least monthly, and major milestones are tracked. Detailed schedule networks and analysis, and monthly status reviews will carry through the implementation phase.

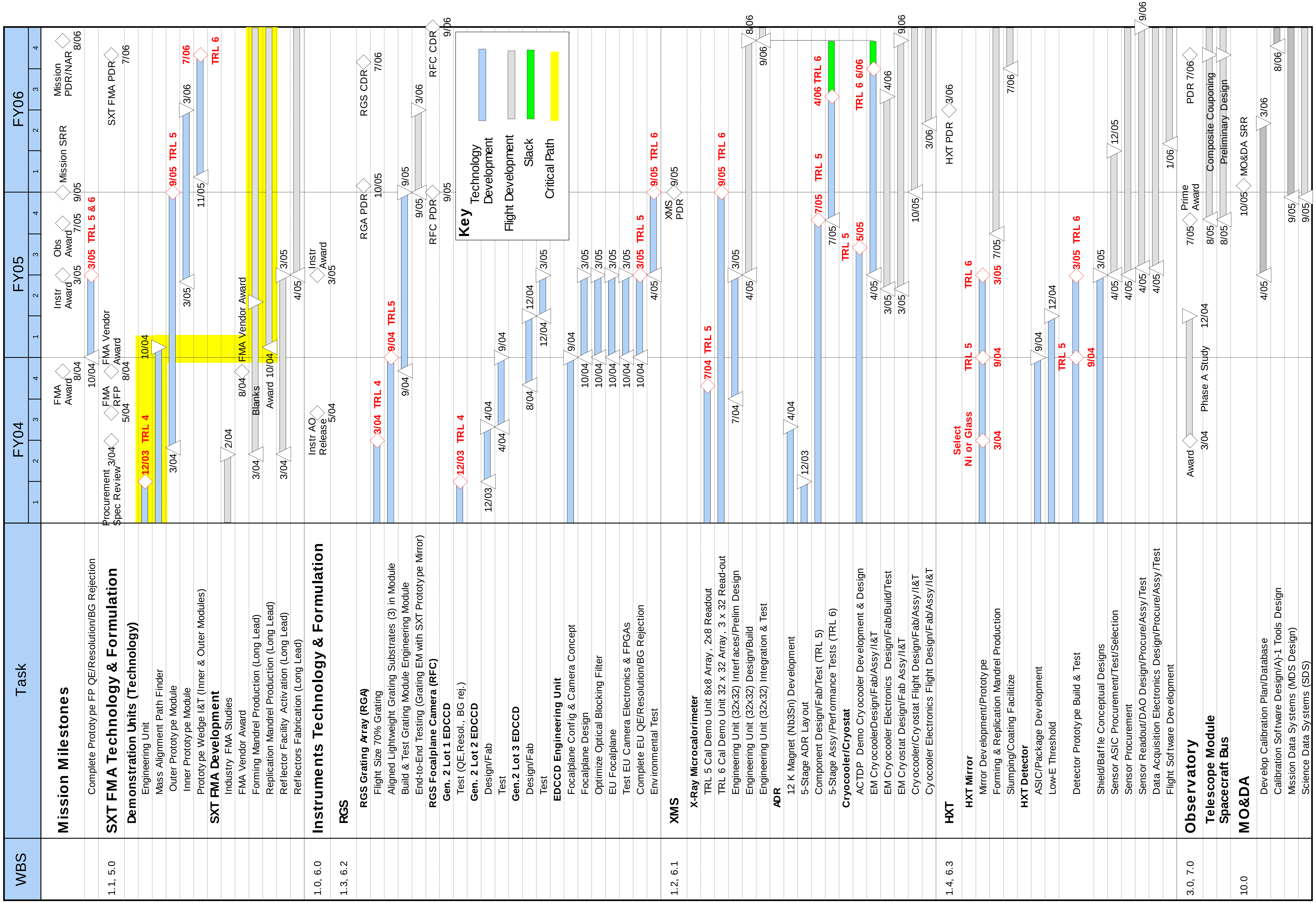
4.3 Budget

This Section Omitted

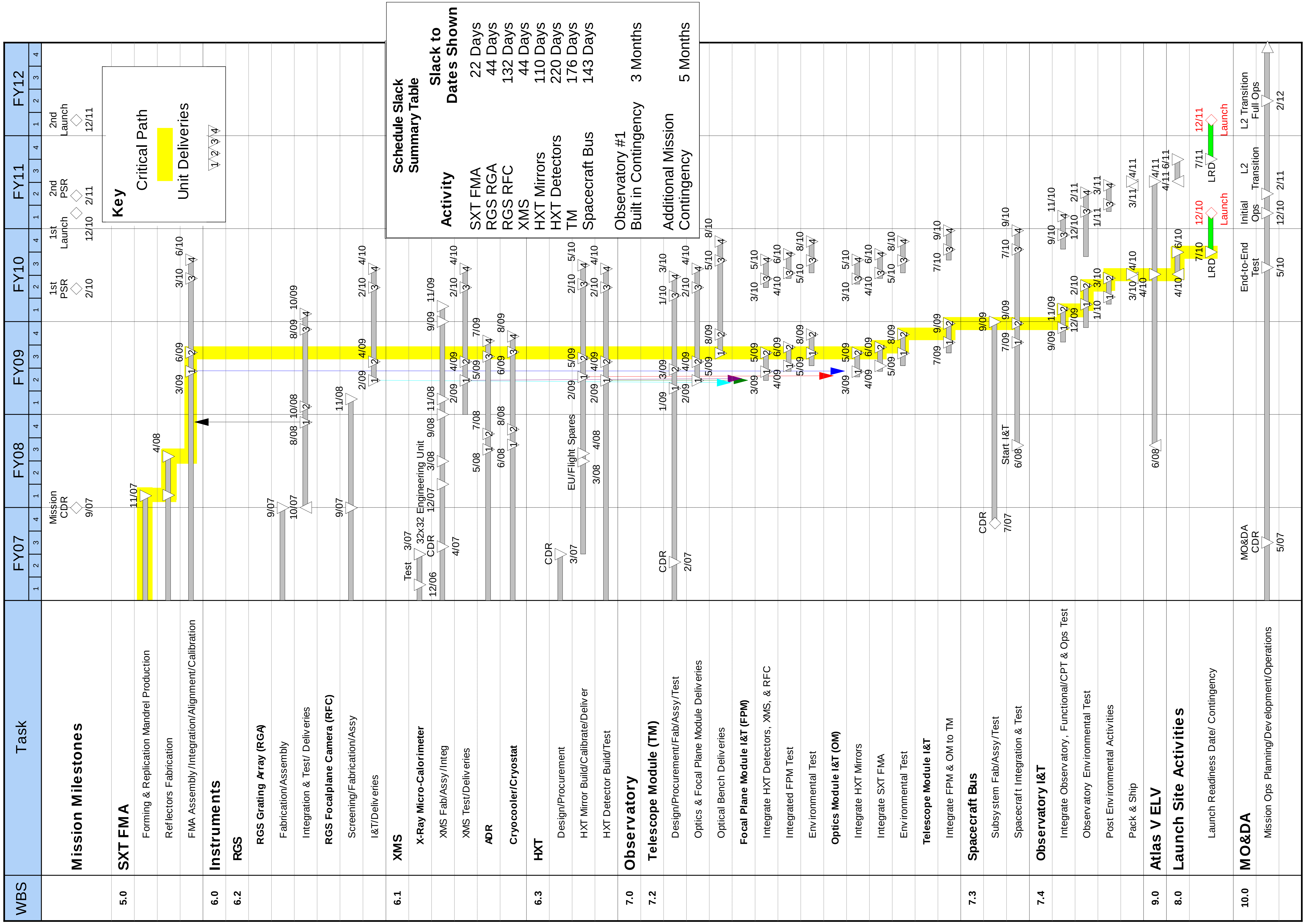
Constellation-X Summary Schedule



Constellation-X Mission Formulation Schedule



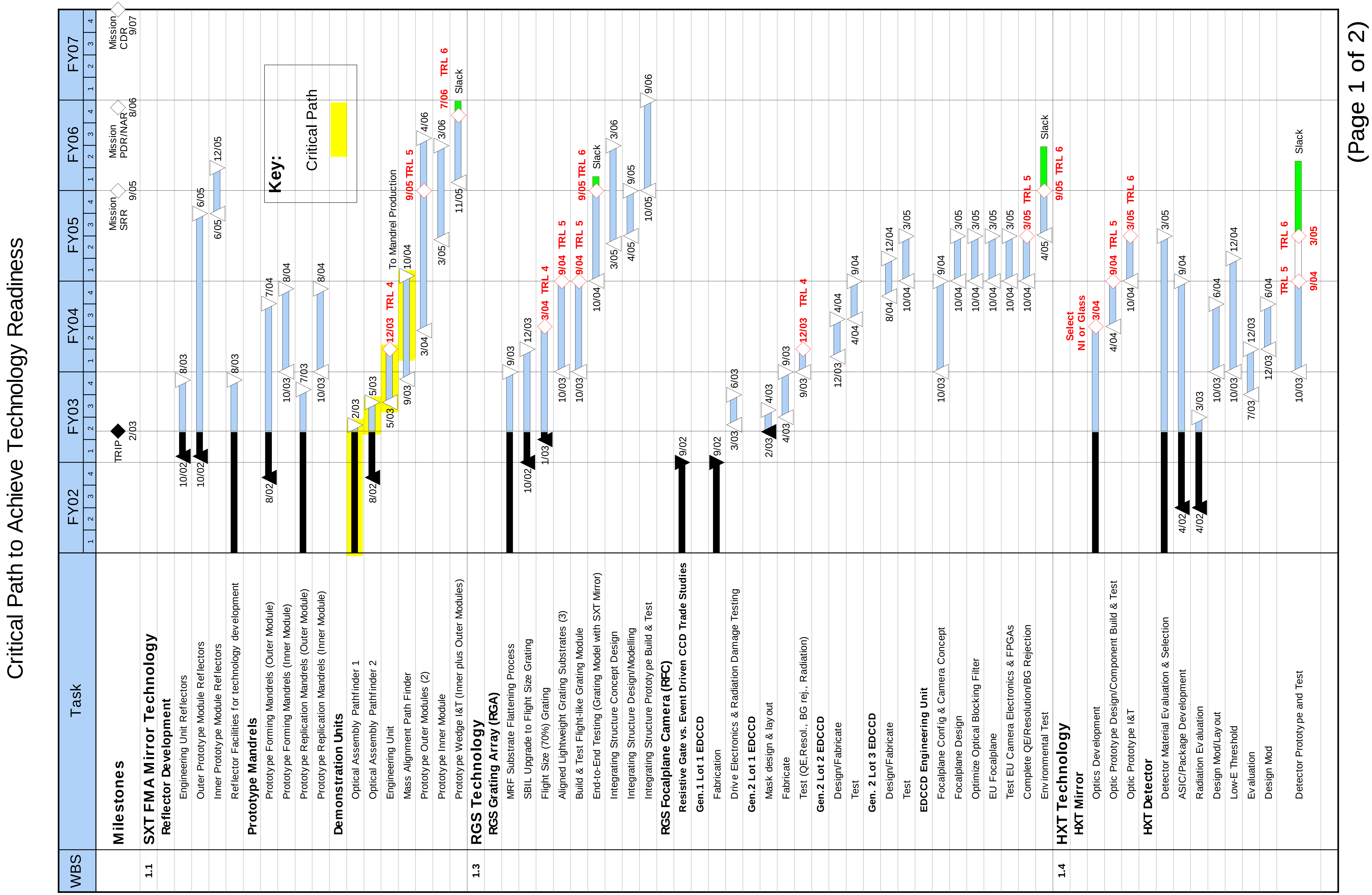
Constellation-X Mission Implementation Schedule



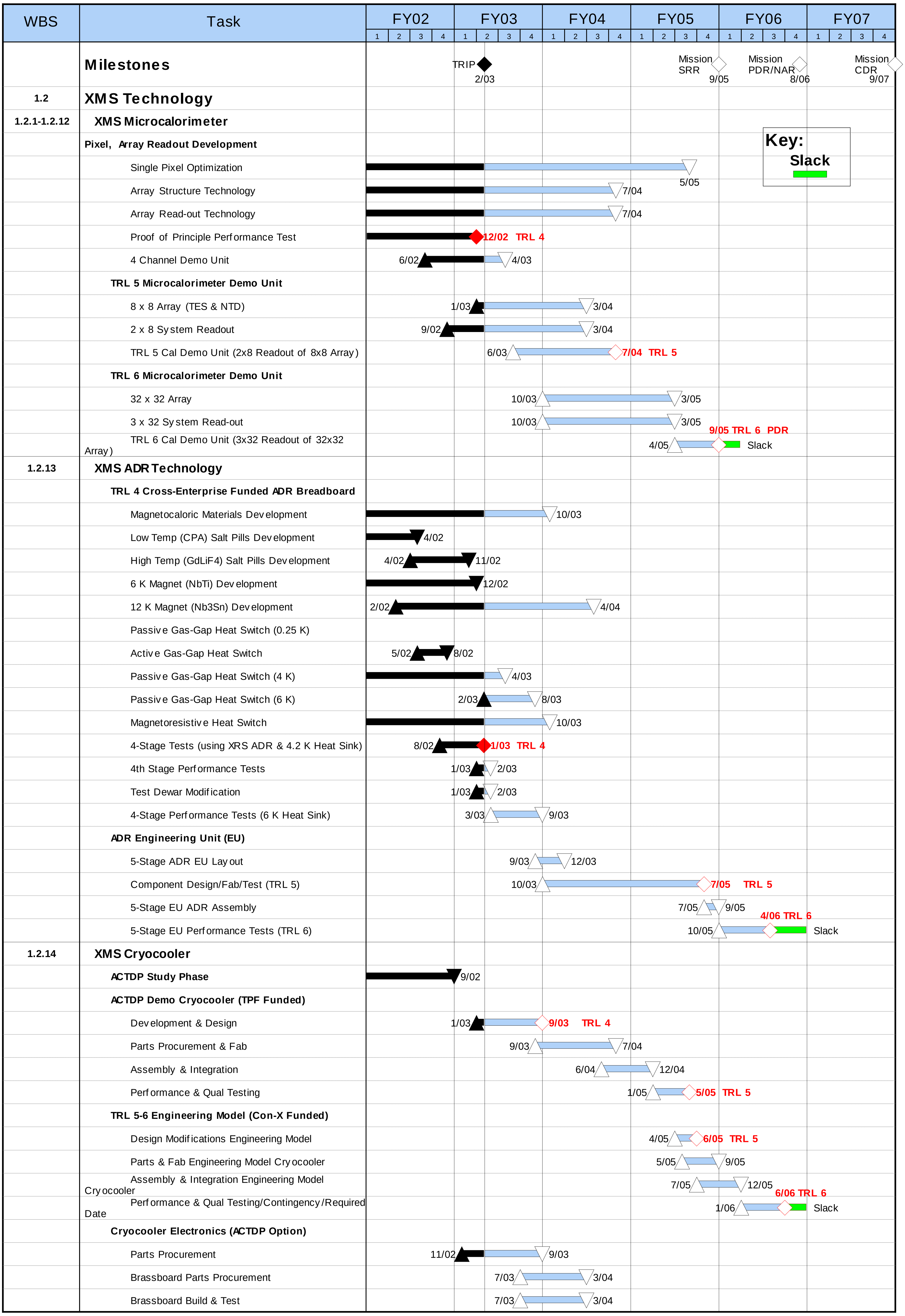
Schedule Slack Summary Table

Activity	Slack to Dates Shown
SXT FMA	22 Days
RGS RGA	44 Days
RGS RFC	132 Days
XMS	44 Days
HXT Mirrors	110 Days
HXT Detectors	220 Days
TM	176 Days
Spacecraft Bus	143 Days
Observatory #1 Built in Contingency	3 Months
Additional Mission Contingency	5 Months

Constellation-X Technology Development Schedule



Critical Path to Achieve Technology Readiness



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